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The Use of Otoacoustic Emissions in Clinical Diagnosis of Hearing Loss in Canines

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THE USE OF OTOACOUSTIC EMISSIONS IN CLINICAL DIAGNOSIS OF HEARING LOSS IN CANINES

A Doctoral Scholarly Project Submitted in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Audiology

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Department of Audiology & Speech-Language Sciences

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This Doctoral Scholarly Project by: Morgan Ashby

Entitled: *The Use of Otoacoustic Emissions in Clinical Diagnosis of Hearing Loss in Canines*

has been approved as meeting the requirement for the Degree of Doctor of Audiology in the College of Natural and Health Sciences, Department of Audiology and Speech-Language Sciences.

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ABSTRACT

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Otoacoustic emissions are an essential part of the audiology test battery, especially for patients who cannot appropriately respond during subjective tests. Otoacoustic emissions provide information regarding the function of the inner ear, specifically the outer hair cells within cochlea. This testing has been done previously in canines in laboratory settings and has shown to accurately diagnose hearing loss in canines verified by brainstem auditory evoked response. There are currently no established protocols, which means no clinical normative data could be established and utilized. The purpose of this project was to review the use of otoacoustic emissions in humans and canines and to discuss factors that could affect otoacoustic emissions in canines to assist in establishing a proposed protocol. This project found otoacoustic emissions are a reliable way to assess hearing of canines and can be used as a screening tool or as part of a diagnostic battery.

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LIST OF ABBREVIATIONS

BAER	Brainstem Auditory Evoked Response
DPOAE	Distortion Product Otoacoustic Emission
OAE	Otoacoustic Emission
SNR	Signal to Noise Ratio
SPL	Sound Pressure Level
TEOAE	Transient Evoked Otoacoustic Emission

CHAPTER I

INTRODUCTION TO OTOACOUSTIC EMISSON USE IN CANINE POPULATIONS

Otoacoustic Emissions in Canines: Benefits and Limitations

Otoacoustic emissions (OAEs) have been used for years to measure hearing status in humans, especially infants who, like canines, are unable to respond during behavioral tests. Currently, the gold standard for hearing evaluation in canines is the brainstem auditory evoked response (BAER), which is more expensive, invasive, and time consuming when compared to otoacoustic emissions. Otoacoustic emissions could be used as a quick screening tool for canines or could be used in conjunction with BAER testing to provide a detailed diagnostic test battery.

Lisa Scheifele et al. (2012) discussed the importance of recognizing and diagnosing hearing loss in canines. Hearing loss in canines might require medical treatment or unique training techniques depending on the type of hearing loss. The researchers stated that many safety hazards might arise when owning a dog with hearing loss. Owners who have a dog with hearing loss should be provided with proper resources and information on managing and training a dog with hearing loss; therefore, it is important to be able to accurately diagnose hearing loss in canines.

Purpose of This Study

This document reviewed the history and physiology of otoacoustic emissions and how otoacoustic emissions related to the canine auditory system. This document also reviewed and evaluated studies that have performed otoacoustic emissions in canines. Limitations and influential factors are addressed along with approaches to the limitations and clinical problems.

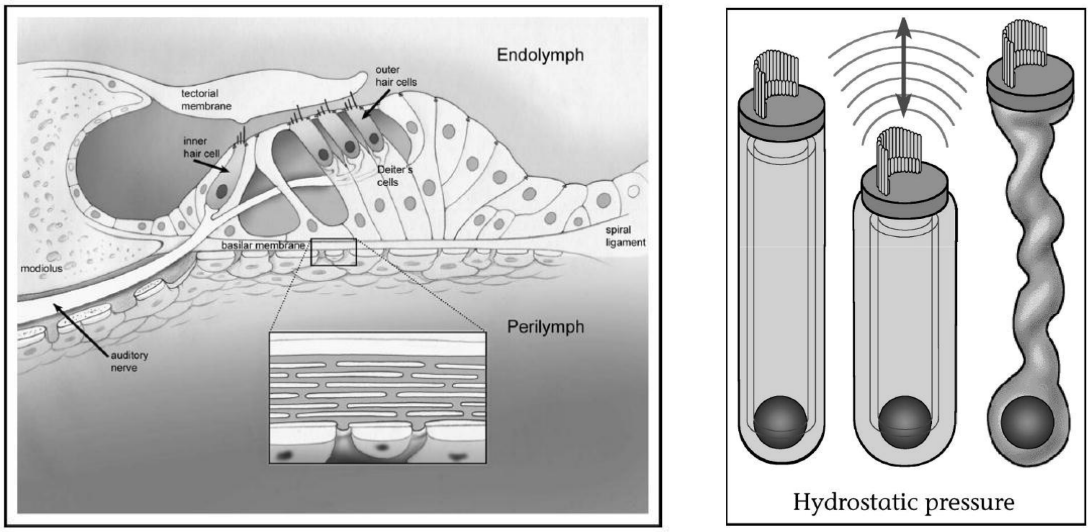
Description of Otoacoustic Emissions

Researchers have found the cochlea, the hearing organ of the inner ear, has both passive and active mechanisms. The passive mechanism, referred to as the traveling wave, is a pressure wave transmitted along the length of the cochlea. The wave's maximum displacement occurs at the corresponding frequency on the tonotopically organized basilar membrane (Oghalai, 2004). The active mechanism, referred to as the cochlear amplifier effect, amplifies the traveling wave to give a 50 dB gain in hearing ability in healthy, live ears. This mechanism occurs in the outer hair cells that sit on the basilar membrane.

There are approximately 12,000 to 13,000 outer hair cells in the human cochlea. These hair cells sit on the basilar membrane, which is housed in the organ of Corti within the cochlea. The anatomy of the cochlea is displayed in the first image in Figure 1. The outer hair cells have movement and motility due to their placement on the basilar membrane and the proteins actin, myosin, and prestin that aid in their ability to stretch and elongate (see the second image in Figure 1). The organ of Corti in the inner ear responds to auditory stimuli by vibrations, which cause the basilar membrane where the outer hair cells sit, to vibrate. This movement of the basilar membrane, in combination with the elongating of the outer hair cells, causes the stereocilia of the cells to deflect against the tectorial membrane, which causes the cochlear amplifier effect. This effect can be measured by otoacoustic emissions. Outer hair cells that are damaged do not elicit an echo back out the ear and, therefore, have absent otoacoustic emissions.

Figure 1

Anatomy and Physiology of the Cochlear Amplifier Effect



Note. Oghalai (2004); Permission granted by Wolters Kluwer Health, Inc.

Otoacoustic emissions are recorded with a probe that is inserted into the ear canal, which emits a specific sound into the ear and then measures the inner ear’s response to that sound. Two types of otoacoustic emission tests are commonly used in diagnostic evaluations and screening assessments: distortion product otoacoustic emissions (DPOAE) and transient-evoked otoacoustic emissions (TEOAE). The stimuli for the TEOAE are 80-85 dB sound pressure level (SPL) clicks while the stimuli for the DPOAE are two tones, labeled F1 and F2, that are 65/55 dB SPL (Kemp, 2002a) with the standard F2:F1 ratio of 1.20 (Hall, 2015a).

Although both TEOAE and DPOAEs are quick, noninvasive tests, TEOAEs can analyze the cochlear function more rapidly since the OAE frequency responses are displayed simultaneously unlike the DPOAEs that must run through each frequency point one at a time sequentially (Kemp, 2002a). The quicker test time may be one reason why professionals may prefer TEOAEs over DPOAEs for newborn hearing screenings (Kemp, 2002b).

One advantage of DPOAEs is they measure higher frequencies compared to TEOAEs. Distortion product otoacoustic emissions can measure up to 16,000 Hz, and this makes DPOAEs a useful clinical tool in monitoring drug-induced hearing loss (Dhar & Hall, 2012).

Transient-evoked otoacoustic emissions can be seen in patients with hearing loss up to 30 dB (Probst et al., 1987). Distortion product otoacoustic emissions can be observed in some patients with hearing loss up to 50 dB because responses can occur with DPOAEs while using a higher stimulation level (70 dB SPL), which cannot be done with TEOAEs (Kemp, 2002b).

Transient-evoked otoacoustic emissions are not as reliant on a low noise floor compared to DPOAEs (Kemp, 2002a). For example, if the noise floor in a response is high due to ambient noise or movement during DPOAEs, the response hides behind the noise floor but with TEOAEs, a response can still be seen and interpreted even with a high noise floor (Hall, 2015a). Analyzing TEOAEs can be done by looking at the band graph and/or spectrum, which allows for in-depth analysis and interpretation. A picture of TEOAE results (bar graph and spectrum) is displayed in Figure 2. Distortion product otoacoustic emissions are displayed on a graph called a DP gram, which is shown in Figure 3.

Figure 2

Image of Transient-Evoked Otoacoustic Emission Results

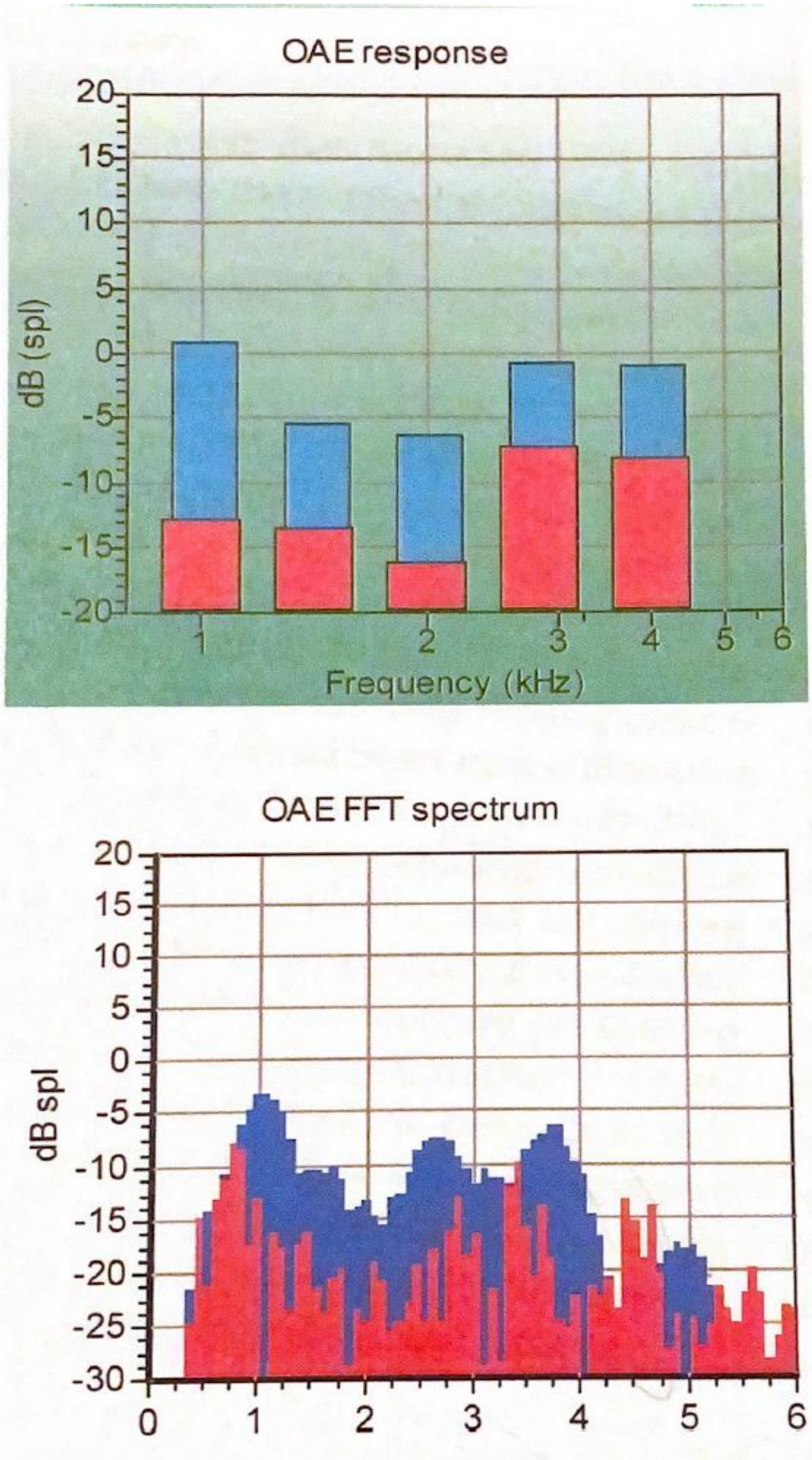
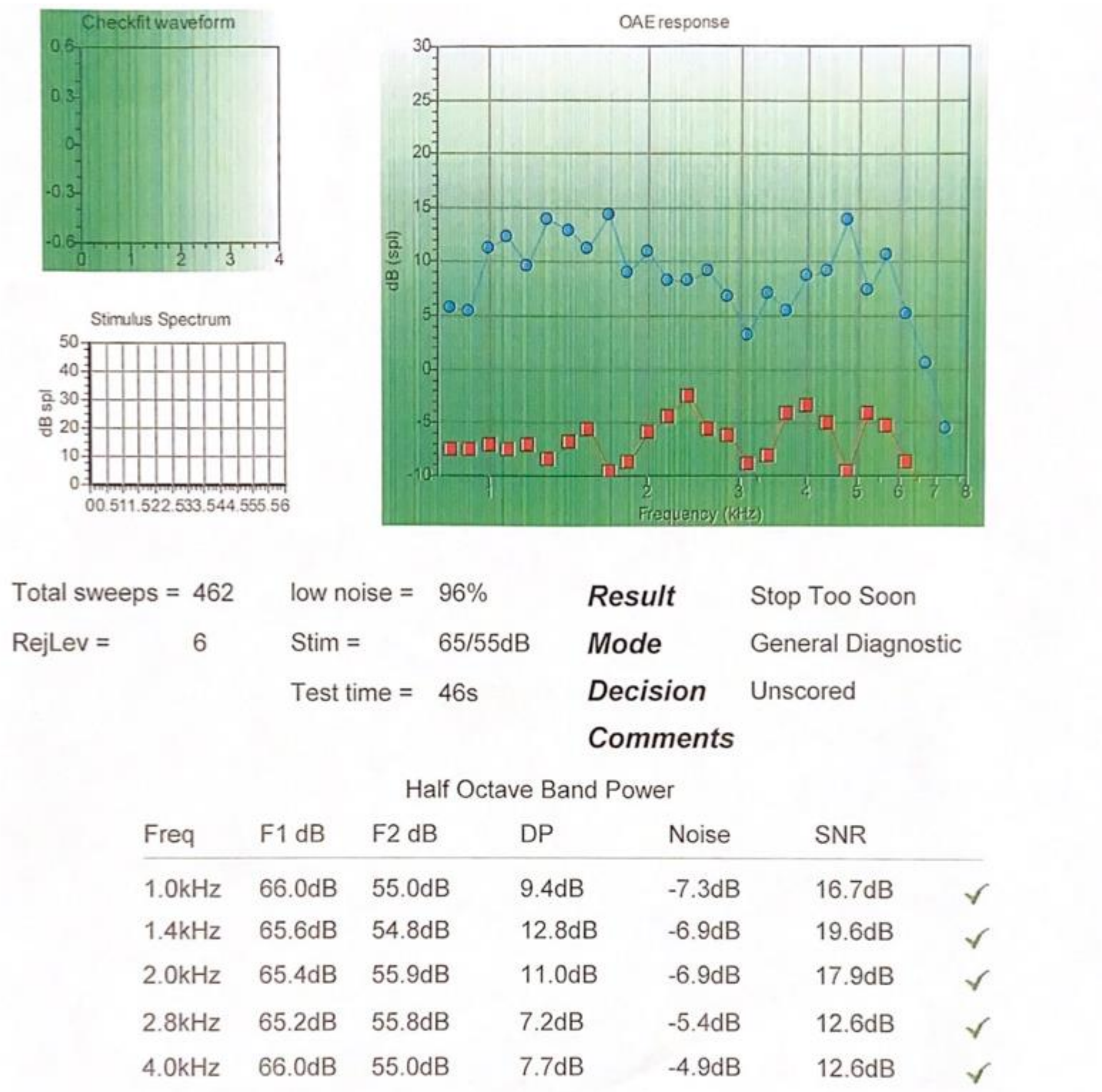


Figure 3

Image of a DP Gram



Interpretation of otoacoustic emissions varies depending on screening or diagnostic equipment. Automated equipment that is typically used as a screening tool has specific criteria and displays a simple pass or fail based on otoacoustic measurement. Diagnostic equipment provides more detailed information about the otoacoustic emissions and professionals are able to evaluate the response.

Signal-to-noise ratio (SNR) is used to interpret the otoacoustic emission. Signal refers to the response from the patient and the noise floor is the ambient noise, noise from the patient, or movement from the patient. The response of the otoacoustic emissions is measured as amplitude and the noise floor is measured in dB SPL. The accepted criterion is typically 3-6 dB SNR, meaning the OAE response should be 3-6 dB above the noise floor and the exact criterion value varies among clinics, manufacturers, and equipment (Musiek & Baran, 2006). The amplitude of the response should also be taken into consideration when analyzing the otoacoustic emission to establish if the otoacoustic emission is present and normal, present and abnormal, or absent (Hall, 2015a). Otoacoustic emissions that meet the SNR criteria but have low amplitude of 0 dB or less should be investigated further as the response may be considered present but abnormal. The number of sweeps displays the number of noisy responses and the number of quiet responses. To ensure accuracy, it is common that the number of accepted or quiet sweeps equals 200 or more. Interpretation of otoacoustic emissions in humans is discussed in Chapter III. Although otoacoustic emissions are not a hearing test, they provide information on the status of the auditory system, specifically the outer hair cells within the cochlea.

Historical Context

Kemp (1978) was the first to record otoacoustic emissions in the human ear and hypothesized that the noise produced by the ear was due to the nonlinearity of the system, precisely due to the cochlea. Since then, more researchers have investigated the cochlear amplifier effect and its contribution to otoacoustic emissions. Researchers have also investigated the effectiveness of otoacoustic emissions in a clinical setting. Otoacoustic emission testing is a common objective screening tool, especially for infants and patients who are unable to perform behavioral tests. Otoacoustic emission testing is also used as a diagnostic tool in clinics. Other uses of otoacoustic emission testing include monitoring ototoxicity, screening for noise-induced hearing loss, and identifying non-organic hearing loss and auditory neuropathy.

Rozario et al. (2014) stated the early detection of hearing loss in children is critical to the growth of speech and language development. Newborn babies are tested under the Joint Committee on Infant Hearing’s (2019) newborn hearing screening protocol to identify children who are born with congenital hearing loss and who will need follow-up and further evaluation after being released from the hospital. The American Speech-Language-Hearing Association (n.d.) reported that 96.1% of babies born in the United States had their hearing screened before one month of age. The American Speech-Language Hearing Association stated both ABR and OAE are used to screen the newborn population because they do not require a response from the patient, they are noninvasive, and they are available in automated versions that allow for simple interpretation by trained staff.

Rozario et al. (2014) conducted a cross sectional study that utilized OAEs and ABR testing on 1,000 newborn infants. The infants in this study were initially screened with DPOAEs and if a child did not pass, they were screened again with DPOAEs. The children were then screened with ABR if they did not pass the second round of DPOAE. Overall, they found 119 infants did not pass the initial screen but after completing the second round of OAE and ABR, only four infants with hearing loss were detected. They concluded that initial OAE screen followed by ABR for children who did not pass were helpful in identifying hearing loss for early intervention.

Kumar et al. (2017) conducted a cohort study by evaluating the use of otoacoustic emissions as part of the universal hearing screening in newborns. The researchers first used transient evoked otoacoustic emission to screen for hearing loss. For those who did not pass the first time, distortion product otoacoustic emissions were then utilized. Lastly, auditory brainstem response testing was used to confirm the hearing loss in the newborn who did not pass both otoacoustic emission screenings. Although the goal of the study was to analyze the incidence of hearing impairment in neonates and determine significance of risk factors in newborns, the researchers found they preferred the use of otoacoustic emissions over auditory brainstem response for the initial screening. The researchers stated they preferred otoacoustic emissions because previous literature that compared the auditory brainstem responses and otoacoustic emissions rated otoacoustic emissions higher, meaning it was preferred by researchers for the initial screening.

Georgalas et al. (2008) studied the effectiveness of TEOAEs to screen for hearing loss and middle-ear effusion in school-aged children. The researchers found that utilizing TEOAEs during a mass school screening was feasible as researchers were able to test all children without a soundproof room and did not exceed 10 minutes per child. Georgalas et al. found that as a single screening modality, OAEs had 100% sensitivity in diagnosing hearing loss worse than 30 dB. Cedars et al. (2018) analyzed the effectiveness of otoacoustic emissions in preschool hearing screenings. They similarly found otoacoustic emissions increased identification of hearing loss, reduced referral rate of children who struggled with conditioned play audiometry, and improved follow-up rates. These researchers found otoacoustic emissions were a quick, reliable way to better understand cochlear function in children.

Saravanappa et al. (2005) studied another use for otoacoustic emissions: as a diagnostic tool for pseudohypacusis in children. The researchers stated that an underlying psychological problem in children often caused pseudohypacusis, which caused children to give inaccurate responses on subjective tests. In this retrospective case-notes review, the researchers found otoacoustic emissions were a quick, objective way to confirm hearing status to aid in the diagnosis of pseudohypacusis when children were unable to give accurate responses during pure tone audiometry.

Otoacoustic emission results provide ear specific and frequency specific information. Hall (2015b) stated there are many advantages to utilizing otoacoustic emissions: they can be portable; they are quick, noninvasive, and inexpensive; they are sensitive to damage before it affects the hearing thresholds of pure tones; and they add validity to any test battery. As in infants, this makes otoacoustic emissions a suitable tool to test hearing in canines. Otoacoustic emission test instrumentation can be brought into veterinary offices and can be transported to a specific room or where the canine feels most comfortable. The quick testing procedure makes otoacoustic emissions suitable for testing canines as they do not have to sit still and quiet for a long period of time. Compared to BAER testing, emissions are less invasive and do not require the use of electrodes, insert earphones, or multiple pieces of equipment. Contraindications of testing otoacoustic emissions are discussed in Chapter III.

Summary of Chapter I

Otoacoustic emissions are sounds of cochlear origin and can be recorded with equipment to evaluate the status of the hair cells within the inner ear. The two types of otoacoustic emissions, TEOAE and DPOAE, have many uses in humans including testing for pseudohypacusis, newborn and infant screenings, school screening, ototoxicity monitoring, and diagnostic evaluations. Otoacoustic emissions do not require a response from a patient, making them suitable for patients who cannot properly response to pure tones. The use of otoacoustic emissions in humans can be comparable to their use in canine populations.

CHAPTER II

REVIEW OF THE LITERATURE

Canine Auditory System

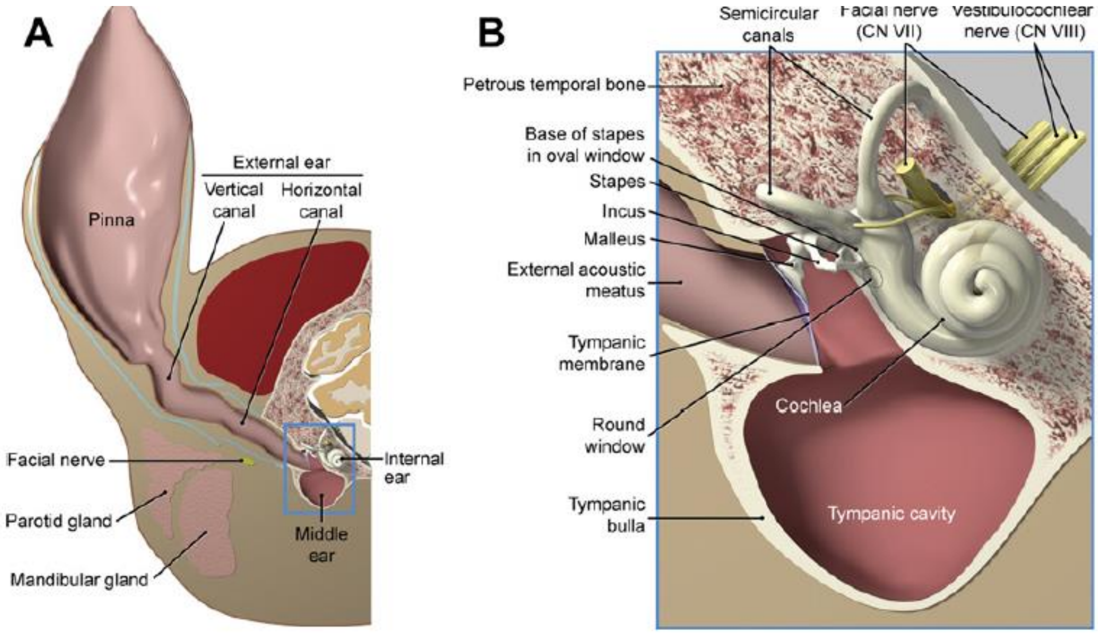
The anatomy and physiology of the canine auditory system have many similarities and differences compared to those of humans. An illustration of the canine ear is displayed in Figure 4. One big difference between canine and human hearing is canines hear significantly better at high frequencies. More specifically, researchers found dogs required minimal acoustic power-level near 4000 Hz while humans heard best at 1000 to 2000 Hz (Lipman & Grassi, 1942). According to Strain (2012), canines can hear 67 Hz to 45 kHz while humans can hear frequency ranges from approximately 20 Hz to 20 kHz in healthy ears.

The most lateral portion of the auditory system, the pinna, is mobile in canines. According to Njaa et al. (2012), canine pinnae can be erect or pendulous and the size and shape of the pinnae are dependent on the breed of the dog. The pinna is responsible for the localization of sound and funneling sound into the external auditory meatus. Similar to humans, canines have ceruminous and sebaceous glands that produce cerumen in the external auditory meatus. Canines typically have hair present in the ear canal, which decreases in abundance from distal to proximal (Cole, 2009). One of the most significant distinctive features of the canine external acoustic meatus when compared to humans is it is composed of two parts: the vertical ear canal and the horizontal ear canal. The more lateral portion of the external auditory meatus is composed of the vertical ear canal, which then becomes the horizontal ear canal. A cartilaginous portion, informally called Noxon’s Ridge, separates the two portions of the ear canal and takes a 90-

degree turn into the horizontal ear canal (Njaa et al., 2012). Once sound travels to the external auditory meatus, it is then funneled toward the tympanic membrane.

Figure 4

Anatomy of Canine Ear



Note. Njaa et al. (2012); permission granted by Elsevier.

The tympanic membrane in canines is very similar to that of humans. It sits at a 45-degree angle and is made up of three layers: epithelium, fibrous connective tissue, and stratified squamous epithelium (Cole, 2009). The pars tensa is the superior portion of the tympanic membrane and the pars flaccida is the inferior portion of the tympanic membrane. The stria mallearis is the part of the tympanic membrane that connects to one of the middle ear ossicles called the malleus. The tympanic membrane vibrates in response to sound waves that travel from the outer ear (Njaa et al., 2012). The movement of the tympanic membrane initiates the oscillation of the connected malleus, causing the rest of the connected bones of the middle ear to move.

The air-filled middle ear consists of three small bones, referred to as the ossicles or ossicular chain. The three middle ear bones are the malleus, incus, and stapes, which are also present in the human ear. Within the middle ear cavity is a connection to the nasopharynx, which is referred to as the Eustachian tube. The Eustachian tube has the similar function in dogs and humans and is responsible for equalizing pressure changes within the middle ear; dysfunction of the Eustachian tube could cause otitis media in canines (Webb, 2009). Similar to the middle ear of humans, there are two muscles within the middle ear space: the tensor tympani and stapedius muscle. Some researchers have stated that by contraction, these muscles aid in protecting the ear from loud sounds (Cole, 2009). The vibration of the ossicular chain causes the transmission of sound signals to the inner ear via the stapes footplate. The footplate of the stapes connects to the oval window, which contacts the perilymph of the inner ear (Cole, 2009); at this stage, the sound is represented in the inner ear.

The fluid-filled inner ear of canines includes the hearing organ, the cochlea, and vestibular organs, the semicircular canals. The membranous structures of the inner ear membranous labyrinth are encased in a bony structure called the bony labyrinth. The main structure of the inner ear, the cochlea, is arranged tonotopically and is vital for detecting sound (Strain, 2012). The cochlea is a coiled structure that contains fluid-filled sections. West (1985) found that canines typically have 3.25 spiral turns, while humans have approximately 2.75 spiral turns of the cochlea, which likely results in a canine’s ability to hear higher frequencies than humans.

Two sections of the cochlea, the scala vestibuli and scale tympani, are filled with a fluid called perilymph. The scala media, or cochlear duct, is in between the scala tympani and scala vestibuli and is filled with a fluid called endolymph. The scala tympani and cochlear duct are separated by the basilar membrane and the scala vestibuli and cochlear duct are separated by Reissner's membrane (Njaa et al., 2012). On top of the basilar membrane is the organ of Corti, which includes one row of inner hair cells and three to five rows of outer hair cells that are vital for amplifying and transducing sounds (Strain, 2012).

As the stapes of the middle ear push on the fluid in the inner ear, excitation of the basilar membrane occurs. The motion on the basilar membrane causes shearing of the stereocilia of the hair cells on the stable tectorial membrane to send impulses to the cochlear branch of the vestibulocochlear nerve, which then sends signals to the auditory portion of the brain (Njaa et al., 2012). As previously discussed, the motility of the outer hair cells is vital as it causes the phenomenon referred to as the cochlear amplifier effect in canines just as it does in humans.

Similar to the human ear, the canine inner ear generates sounds, either spontaneously or in response to a stimulus (Strain, 2012), which are referred to as otoacoustic emissions. The proteins of the outer hair cells allow rapid contraction of the hair cells in response to sound. The outer hair cell stereocilia are arranged in a W formation and are linked to the production of otoacoustic emissions (Scheifele & Clark, 2012). Scheifele and Clark (2012) stated that a normal cochlea not only receives sounds via the external auditory meatus but also produces sounds.

Once sound reaches the hair cells of the inner ear, the sound signal is sent to the auditory cortex of the brain. The hair cells can be referred to as mechanoreceptors and the direction the cilia of the hair cells move determines whether the cell becomes hyperpolarized or depolarized (Njaa et al., 2012). Depolarization of the hair cells causes the release of a neurotransmitter that is relayed to the vestibulocochlear nerve and then to the auditory portion of the cerebral cortex (Webb, 2009).

Hearing loss in canines is common and has a variety of causes. Although sensorineural hearing loss from congenital hereditary cause is the most common, other types of hearing loss occur as well (Strain, 2012). Conductive hearing loss in canines could be caused by excessive cerumen or foreign bodies, otitis externa, otitis media, ear canal atresia, and other abnormalities of the outer or middle ear. Primary secretory otitis media is an ear infection with effusion, known as glue ear, in canines that causes conductive hearing loss and does have a congenital cause in the Cavalier King Charles spaniel breed (Strain, 2012). Most conductive hearing loss might be resolved with proper treatment and care such as medication or removal of foreign bodies.

Sensorineural hearing loss, which originates from the inner ear or the auditory nerve, cannot be treated and is permanent. Sensorineural hearing loss in canines can be divided into two categories: hereditary and acquired. Acquired hearing loss can occur from ototoxic medication, otitis interna, presbycusis, noise trauma, or idiopathic hearing loss (Strain, 2012). Strain (2012) stated that pigment-associated hearing loss was the most common hereditary hearing loss and occurred most often in canines with white or dilute pigmentation and in canines with blue irises. The researcher stated that pigment-associated hearing loss was specifically associated with recessive alleles or the piebald gene or the dominant allele or the merle gene. Studies reviewed by Strain (2012) found at least 90 different breeds had congenital hearing loss with the highest prevalence in Dalmatians; 30% of Dalmatians in the United States are born with hearing loss. Strain also discussed the bilateral congenital deafness in Doberman pinschers and hereditary hearing loss related to anxiety disorders and/or inbreeding in Pointers.

Currently, limited research exists on otoacoustic emissions in canines but with the similarities between the human auditory system and canine auditory system, we could infer that the otoacoustic emissions would act similarly in canines as they did in humans. With a variety of causes of hearing loss in canines, adding otoacoustic emissions to the test battery of canines could provide more information about the status of the outer hair cells.

Brainstem Auditory Evoked Response Testing in Canines

Brainstem auditory evoked response, commonly referred to as BAER testing, is the primary method for assessing canine hearing (Gonçalves et al., 2012). Evoked potentials are voltage changes that occur in a response to a stimulus that are picked up from electrodes (Webb, 2009). Brainstem auditory evoked response testing can be done on canines that are at least 35 days old, and canines must pass in both ears to be considered an overall pass according to the Orthopedic Foundation for Animals (Strain, 2020). Recommended parameters of the testing are defined and displayed in Table 1. The following are steps to the canine BAER screening protocol, which could be performed by a veterinarian professional or an animal audiologist:

1. The canine is prepped with numbing cream, lidocaine/prilocaine, where the electrodes are placed. Subdermal electrodes are placed under the skin at the vertex (Cz) and just forward of the tragus at both ears (A1 and A1).
2. Insert earphone is placed in the test ear.
3. Click stimuli are presented to the ear and the response is measured twice for repeatability.
4. The insert earphone is placed in the other ear and testing is performed again.
5. Waveforms are analyzed and interpreted on the computer.

Table 1

Recommended Parameters for Brainstem Auditory Evoked Response Testing

Parameter	Definition	Suggested Parameter for Baer Testing
Amplifier	Used to amplify the signal due to the small amplitude of the waveform	100,000 to 150,000 absolute gain
Filters	Used to eliminate artifact and noise	300 Hz to 1,500 Hz
Signal Averaging	Averaging the response reduces artifact and background noise	1000 to 2000 sweeps
Stimulus type	Type of sound that will be presented to the canine via the insert earphone, and can evaluate certain areas of the cochlea	Click stimulus with energy between 500-4000 Hz stimulates the 2000-4000 Hz area in the cochlea
Stimulus rate	Number of stimuli presentation per unit of time	33.3 clicks per second
Stimulus intensity	How loud the click will be presented, measured in peSPL during canine BAER testing	Screening level starts at 102 dB SPL

Note. Adapted from Scheifele and Clark (2012).

The interpretation of the waveforms includes evaluation of the wave morphology, repeatability, latencies, and amplitude. For canines, wave I should occur between one and two milliseconds and wave V should occur between four and five milliseconds. Figure 5 displays a normal BAER with labeled peaks while Figure 6 shows a BAER from a canine with hearing loss in the left ear. In Figure 6, the waveform does not have any identifiable peaks, especially when compared to the waveforms in the previous figure.

Figure 5

Normal Canine Brainstem Auditory Evoked Response Waveform with Markings

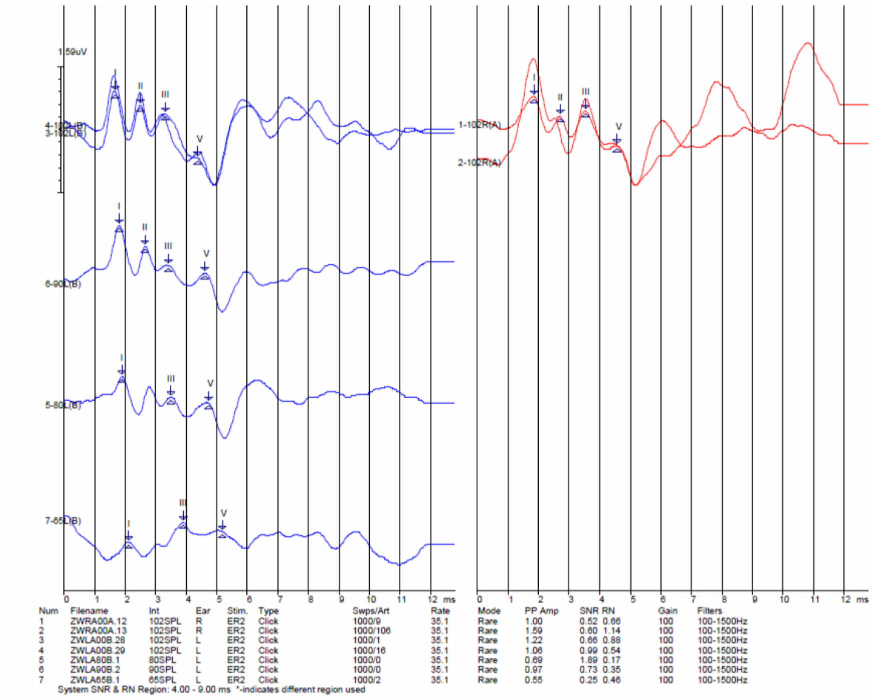
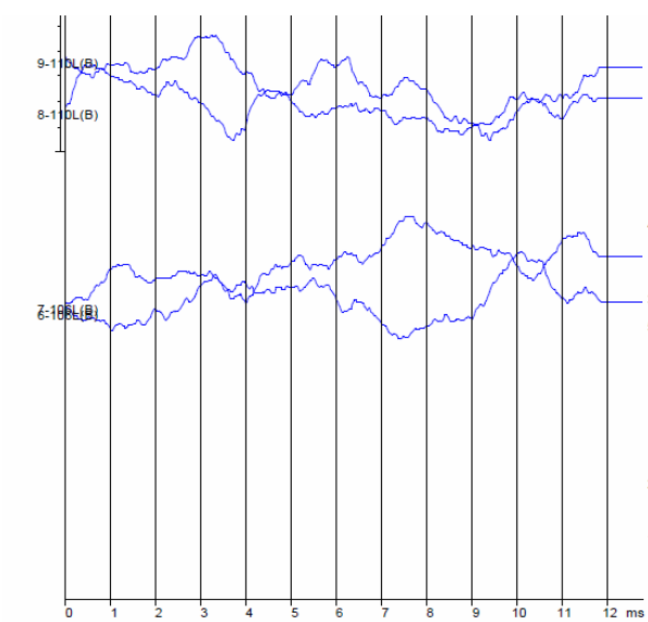


Figure 6

Abnormal Canine Brainstem Auditory Evoked Response Waveform of the Left Ear



One advantage of BAER over OAE was explained by Scheifele and Clark (2012) who stated that similar to human BAER testing, canines with conductive hearing loss would have BAER results with a specific pattern: the waves produced would be prolonged but the interwave latencies would be within normal limits. Otoacoustic emissions would often be absent if there was a significant conductive hearing loss as the sound cannot pass through the outer or middle ear. Scheifele and Clark (2012) also discussed the use of BAER to estimate hearing thresholds. Stimulus levels could be increased and decreased during testing to estimate thresholds and currently, there are no research-based norms for OAE threshold estimation. Brainstem auditory evoked response testing also does not require as much reduction of ambient noise as it does for otoacoustic emissions. Another advantage of BAER testing is it can be used to measure auditory function up to the level of the brainstem (Wilson & Mills, 2006).

Webb (2009) stated that although the channel (electrode) board, amplifier, signal averager, and stimulator could be purchased as one unit from companies, the cost could be high. This cost does not include the continuous cost for supplies needed such as the electrode leads, lidocaine, and earphones. Another disadvantage of BAER testing could be user error including incorrectly marking the peaks of the waveform. Wilson and Mills (2006) stated that errors could occur during testing and interpretation due to inexperienced or inadequately trained professionals.

Brainstem auditory-evoked response testing is slightly more invasive and time consuming compared to otoacoustic emissions. Lastly, the canine must be compliant not only during testing but during the placement of the electrodes, during impedance check of electrodes, and during insert earphone insertion. Wilson and Mills (2006) stated muscular artifact was the most significant invalidator of the BAER recording. Brainstem auditory-evoked response testing also requires minimal noise from the canin, as well as reduction of electrical noise that might cause interference.

Wilson and Mills (2006) reviewed literature of the BAER in canines and discussed the use of BAER testing, advantages and disadvantages of BAER testing, as well as areas that needed further research. They stated that in some areas, research was contradictory. According to Wilson and Mills, there is controversy regarding the effects of head size on the waveform response for BAER tests. Currently, the generation site of BAER waves in canines is still being debated by researchers. Although these factors are still unknown, many researchers have shown that BAER testing is an accurate way to screen for and diagnose hearing loss.

Munro and Cox (1997) performed BAER threshold estimation on nine Cavalier King Charles spaniels with a history of hearing impairment. Brainstem auditory-evoked response results confirmed the owner's suspicion of hearing loss in 88% of the canines and BAER testing revealed more information regarding the site of lesion of the hearing loss by evaluating the latencies to determine if the hearing loss was conductive or sensorineural. Mondino et al. (2018) found consistency in results compared to other studies. Specifically, they stated their BAER on 46 Cimarron Urogayo dogs had similar latencies and amplitude values for waves I to V compared to other canine BAER studies.

Paterson (2017) utilized BAER in 37 dogs with otitis media before and after topical treatment. The researchers were not only able to compare pre-treatment BAER thresholds to post-treatment BAER thresholds but they were also able to monitor ototoxicity of the topical treatments. The researchers stated one limitation to BAER testing was it might be not be clear if the hearing loss was sensorineural or conductive without the completion of air and bone conduction testing.

There are advantages and disadvantages to BAER testing in canines. Brainstem auditory-evoked response is currently the only accepted method of diagnosing genetic congenital hearing loss according to the Orthopedic Foundation for Animals (Strain, 2020); however, there are areas that need to be further researched.

Otoacoustic Emissions in Canines: Current Research

Otoacoustic emissions have the same purpose in canines as they do in humans: to evaluate the function of outer hair cells. In humans, otoacoustic emissions are commonly used for populations that do not need to attend to the test (Scheifele & Clark, 2012), which makes them suitable for canines. Although BAER testing is the only accepted method of diagnosing hearing loss in canines according to the Orthopedic Foundation for Animals (Strain, 2020), Scheifele and Clark (2012) stated that otoacoustic emissions, in combination with BAER testing, could provide a complete auditory assessment in canines.

Studies Utilizing Both Transient-Evoked Otoacoustic Emissions and Distortion Product Otoacoustic Emissions in Canines

Sockalingam et al. (1998) used TEOAE and DPOAE to assess hearing in seven healthy dogs. The researchers used the ILO 92 OAE analyzer by Otodynamics. Testing was done in a quiet room while the dogs were under general anesthesia. The DPOAE F2/F1 ratio was set to 1.22, as it has been used in humans and laboratory mammals to yield the best results. Any DPOAE response above the noise floor was considered to be present. Transient-evoked otoacoustic emissions were measured at 80 dB peSPL between 1000 and 4000 Hz. Any OAE response above the noise floor was considered present. The researchers found five dogs had normal OAE responses in both ears and two dogs had normal hearing responses in the left ear. Results were supported by otoscopy, tympanometry, and BAER. Sockalingam et al. also stated that testing did not typically exceed one minute when using the TEOAE quickscreen program. The researchers concluded otoacoustic emissions had the potential to be used as a quick and reliable screening tool for hearing pathology in canines.

Gonçalves et al. (2012) used TEOAEs and DPOAEs to evaluate the cochlear status of canines. Fifty-three dogs under general anesthesia were included in this study. The researchers used multiple techniques to minimize noise during testing including closing the door of the room, using an ear cover to attenuate noise, and informing others to minimize noise. Otoacoustic emissions were obtained using the Echoport ILO 288 system (Version 6) with Otodynamics probe tips. Otoacoustic emissions were recorded up to three times if dogs did not pass the first or second run.

Transient-evoked otoacoustic emission stimulus level was 90 dB SPL recording frequencies 1000-4000 Hz (Gonçalves et al., 2012). A valid TEOAE response had to meet the following criteria: reproducibility rate of 87% or higher, stimulus equal to or greater than 85 dB SPL and equal to or less than 95 dB SPL, and at least 30 low noise samples per test. Of the valid responses, a 6 dB signal to noise criteria was used except at 1000Hz where 3 dB was considered a pass due to ambient noise. The DPOAE tones ranged from 1000-6000 Hz. The DPOAE ratio used in this study was 1.21, which was based on previous research that had success using this ratio. A 3 dB signal to noise response was needed to be considered a pass at five of the eight frequencies.

Of the 10 dogs that had BAER testing completed, two dogs had absent BAER waveforms and the distortion product and transient-evoked otoacoustic emissions verified their hearing loss by producing a fail for both ears in all three trials (Gonçalves et al., 2012). The normal hearing canines passed in all transient evoked trials and 15 of the 16 ears passed in distortion product trials. The study showed both TEOAE and DPOAE results for a canine with normal hearing and a canine with hearing loss, which was verified by BAER testing. Gonçalves et al. (2012) performed the otoacoustic emissions while the canines were under general anesthesia; therefore, physiological noise or movement of the canines did not have any effect on the results.

Studies Utilizing Distortion Product Otoacoustic Emissions or Transient-Evoked Otoacoustic Emissions in Canines

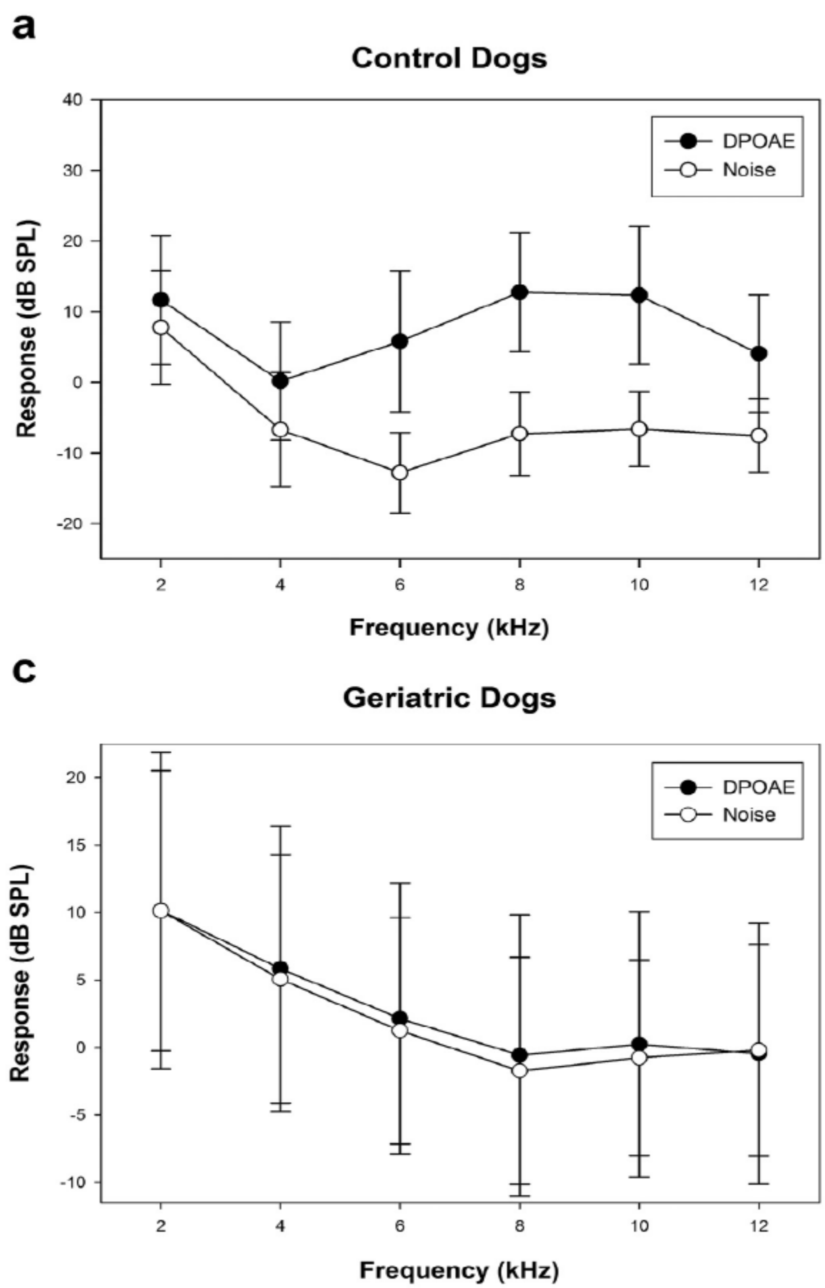
Distortion product otoacoustic emissions were used to assess 23 alert, non-sedated puppies in a study completed by Schemera et al. (2011). Threshold estimation BAER testing was performed to ensure canines had hearing within the normal range. Distortion product otoacoustic emissions were obtained in a quiet, non-sound attenuated room and replicated for validation using a commercially available measurement system. Although no specific dB SPL values were recorded, the researchers stated the room was similar to a quiet room in a veterinary office. The DPOAE ratio was 1.20 measuring 1500-10,000 Hz and a commercially available foam tip was trimmed and used to obtain otoacoustic emissions. The pass criterion was established as 8dB or higher, meaning the otoacoustic emissions had to be 8 dB greater than the noise floor to be counted as a pass. Each measurement was repeated once or twice to ensure repeatability. Schemera et al. found that overall, otoacoustic emissions were easily measured, robust, and consistent with BAER results in 22 puppies. One puppy was excluded due to excessive movement, causing unreliable results.

Rogers et al. (1995) recorded DPOAEs in seven canines that were under general anesthesia. Testing was completed in a sound-attenuating booth. Distortion product otoacoustic emissions were elicited using a F2:F1 ratio of 1.21 measuring 1000-8000 Hz. The researchers modified the intensity levels during trials and found that at 75 dB SPL, reduced responses were obtained in the lower frequencies and at 55 dB SPL, reduced responses were obtained in the low and upper middle frequencies. Overall, they found DPOAEs could be elicited from canines in most frequencies.

Strain et al. (2016) focused on obtaining DPOAEs in geriatric dogs. The researchers' population included 28 dogs with a mean age of 12.2 years and a control group of 15 dogs with a mean age of 5.9 years. Strain et al. tested frequencies 2-12 kHz in 2 kHz increments with a F2:F1 ratio of 1.21. OtoRead Clinical OAE by Interacoustic was used with a disposable 9 mm or 10 mm tip ear probe. Pass criterion was set at 4 dB, meaning the response had to be at least 4 dB greater than the noise floor. The initial BAER testing in the geriatric population showed an overall decreased BAER response (Strain et al., 2016). The otoacoustic emissions of the geriatric population had a significant decrease in amplitude at 6-12 kHz when compared to the otoacoustic emissions of the control group. The researchers of this study concluded that aging affected otoacoustic emissions in canines, especially in the higher frequencies. Figure 7 compares the DPOAE results from the control group and the geriatric group.

Figure 7

Distortion Product Otoacoustic Emissions from Control Group (Top) and Geriatric Group (Bottom)



Note. Geriatric dogs had reduced DPOAE response at high frequencies compared to the control group. Adapted from Strain et al. (2016). Permission granted by Elsevier.

McBrearty and Penderis (2011) screened puppies using TEOAEs on a commercially available OAE system. Probe fit was verified by using the system's Checkfit function. The stimulus used was a broadband click at 90 dB SPL at 1000-4000 Hz. Pass criterion was established as peak stimulus intensity between 85 and 95 dB SPL and reproducibility equal to or greater than 75%. After analysis, the researchers used 6 dB SNR cutoff except at 1000Hz, where 3 dB SNR was used. At least three frequency bands had to meet the pass criterion to be considered an overall pass.

McBrearty and Penderis (2011) tested 40 puppies that were part of a congenital deafness program. Brainstem auditory-evoked response testing was performed first to confirm whether a puppy had a hearing loss. They found transient-evoked testing correctly identified hearing loss in all ears considered to have hearing loss according to BAER tests. The researchers stated that for this study, the sensitivity was 100% and specificity was 78%, which could be due to ambient noise, movement, presences of outer or middle ear analysis.

Summary of the Current Literature: Otoacoustic Emissions in Canines

For diagnostic purposes, otoacoustic emission testing could be used in combination with other tests, such as the BAER test, to confirm results and possibly find the site of a lesion. For screening purposes, otoacoustic emission testing could be used alone or in combination with BAER. Otoacoustic emission tests have been a useful and reliable screening tool in humans and likely could be similarly used in canines. (Schemera et al., 2011). McBrearty and Penderis (2011) stated that the use of otoacoustic emission testing as a screening tool could be used similar to that of infants. Puppies that failed could be retested at a later date and then referred for BAER screening to confirm hearing status.

Summary of Chapter II

The hair cells within the cochleae of canines have similar function to that of humans, which makes otoacoustic emissions a suitable test for assessing the function of the inner ear. With a variety of causes of acquired and hereditary hearing loss in canines, adding otoacoustic emissions to the test battery could provide more information about the status of the outer hair cells. Currently, BAER is the only accepted test to evaluate the hearing of canines. Researchers who investigated otoacoustic emission use in canines found otoacoustic emissions could be a quick, noninvasive, and effective way to assess the hearing status of canines.

CHAPTER III

FACTORS AFFECTING OTOACOUSTIC EMISSIONS USE IN CANINES

Gaps in Literature: Otoacoustic Emissions in Canines

Many studies have shown that otoacoustic emissions were effective in evaluating hearing status in canines; however, there were a lot of limitations and gaps in the literature. Gonçalves et al. (2012), Sockalingam et al. (1998), and Rogers et al. (1995) performed otoacoustic emissions on canines to evaluate hearing of the canine but had their dogs put under general anesthesia. While this would provide an ideal situation to test otoacoustic emissions because movement or noise from the dog would not disrupt testing, it was unrealistic. Otoacoustic emissions are typically a fast, noninvasive way to screen for hearing loss, and putting the canines under general anesthesia would cause it to be more invasive, time consuming, and expensive.

Studies previously discussed also used a laboratory setting where the rooms were controlled and quiet. Rogers et al. (1995) tested their canine participants in a sound-attenuating booth. These settings were unrealistic as canines would likely be tested at a veterinarian's office and those noise levels could not always be controlled and typically were not quiet. Schemera et al. (2011) performed testing in a quiet room and no specific noise levels were measured; therefore, it could not be adequately compared to ambient noise of other settings such as a veterinary office.

The studies previously discussed used a variety of equipment and probe tips to collect their data. Some studies verified probe tip placement and fit while others did not. Only one study mentioned the use of a cup over the ear to hold the probe tip in place. Equipment and probe tips specifically designed for canines should be further investigated to provide consistency between studies and test sessions.

The studies previously discussed used a variety of parameters in their studies. Some studies used DPOAE ratio of 1.20, 1.21 or 1.22. For TEOAES, stimulus chosen was 60dB SPL-90dB SPL. Few studies specifically stated why they chose those parameters but some researchers used data from human otoacoustic emissions studies to set the parameters; thus, it is unknown if these parameters yielded the best results for canines. Researchers had different criteria for which they considered an otoacoustic emissions to "pass." Scheifele and Clark (2012) stated in their research article that a "pass" occurred when the otoacoustic emission response was 4 dB SPL greater than the noise, while other researchers used 3 dB SPL or 6 dB SPL. The discrepancies between studies caused inconsistent interpretation of results. Future research should establish specific criteria for interpreting results, making it clear what is considered normal and abnormal. More research needs to be done in this area to establish what parameters work best in canines.

Interpretation of Results in Human Otoacoustic Emissions

To better understand the gaps within the literature stated above, previous research and parameters in human otoacoustic emissions are discussed. These levels have been established by extensive research and are accepted by clinicians and researchers in the field of audiology.

There are many steps in the analysis of otoacoustic emissions. First, one should verify an adequately low noise floor (Dhar & Hall, 2012). There should be at least 200 sweeps and the number of quiet samples should be high to ensure noise does not affect the accuracy of the responses.

Next, one should verify the stimulus was presented at the appropriate level. The stimulus for TEOAE is 80-85 dB SPL clicks while the stimulus for the DPOAE is two tones at 65/55 dB SPL (Kemp, 2002a) with the frequency of the tones (F2:F1) having a standard ratio of 1.20 or 1.22 (Hall, 2015a). For both TEOAE and DPOAEs, the stimulus should be stable and presented at the correct levels. Hall (2015a) stated for TEOAEs, the stimulus stability rate should be high and anything lower than 50-70% should be discarded and run again. Dhar and Hall (2012) stated that the reproducibility value should be greater than 90%.

Next, it is important to look at the response of the otoacoustic emission in relation to the noise floor. For humans, Hall (2015a) stated that otoacoustic emission are present when the response is 6 dB above the noise floor. For TEOAEs, the responses and noise floor are represented on a bar graph and as a spectrum. For DPOAEs, the responses and noise floor are represented on a DP gram, which graphs the points of the response at the corresponding frequency. Abdala (2018) discussed the importance of accurate interpretation of otoacoustic emissions and stated that a present and normal otoacoustic emission was not only 3-6 dB above the noise floor but also had an appropriate amplitude based on the patient's age. Otoacoustic emissions that are 6 dB above the noise floor might not always be considered normal. Diagnostic interpretation of otoacoustic emissions involves looking at the amplitude of the response at each frequency and should be categorized as normal, abnormal but present, or abnormal (Dhar & Hall, 2012). Lastly, according to Hall (2015a), intra subject repeatability is high; therefore, otoacoustic should be replicated at least twice.

Influential Factors or Considerations

Many elements could influence the results of otoacoustic emission testing. These variables can be separated into two groups: intrinsic and extrinsic factors. Intrinsic factors originate from an individual while extrinsic factors originate outside the person. Intrinsic variables that could affect test results include patient physiologic noise, age, and hearing loss. Extrinsic factors that could occur while obtaining otoacoustic emissions are the fit of the probe tip and the environment where testing occurs.

Intrinsic Factors

One intrinsic factor is physiologic noise, which could include noisy breathing, talking, barking, or crying. Similar to test environments, any noise should try to be reduced; however, these intrinsic situations cannot always be controlled. In a noisy condition, averaging could bring the emission out of the noise floor with time and patience (Robinette & Glattke, 2007). Patients should try to be as quiet and as still as possible during the test time to obtain the most accurate results.

The next intrinsic factor, hearing loss, is an important variable that should be taken into consideration while obtaining otoacoustic emissions. Conductive hearing loss and middle ear problems could cause an inaccurate representation of the hair cell function. Since otoacoustic emissions enter the probe via the middle ear after being produced by the inner ear, the transmission of the sound could be affected if a middle ear pathology was present; therefore, otoacoustic emissions would be absent (Robinette & Glattke, 2007). Xenellis et al. (2008) discovered that the absence of otoacoustic emissions in school-aged children was strongly correlated with tympanic membrane changes seen during otoscopy and the presence of a Jerger Type B tympanogram, which are indicative of a middle ear pathology. Otitis media and middle ear abnormalities cause absent otoacoustic emissions, which does not always mean there is a permanent hearing loss due to the hair cells of the inner ear.

Sensorineural hearing loss could also affect otoacoustic emissions. Probst et al. (1987) found transient evoked otoacoustic emissions could be recorded in ears with sensorineural hearing loss up to 30 dB HL. Although retrocochlear pathologies are known to be beyond the cochlea and typically do not affect otoacoustic emissions, Gouveris et al. (2007) found otoacoustic emissions were absent in patients with vestibular schwannomas or tumors on the eighth cranial nerve. The researchers stated vestibular schwannomas could cause degeneration of the inner ear, especially the inner and outer hair cells; therefore, otoacoustic emissions could be absent in patients with tumors around the inner ear.

Similarly, age-related hearing loss might affect otoacoustic emissions. Ortmann and Abdala (2016) analyzed the differences in distortion product otoacoustic emissions by controlling for age. The participants' ages ranged from 18 to 64 years. The researchers discovered that older ears had reduced distortion product otoacoustic emission amplitude when compared to younger ears. Hoth et al. (2009) analyzed a database of 5,142 patients ranging from 0.4 to 89.8 years of age. The researchers compared OAE results to audiometric thresholds to determine whether the OAE amplitude decrease was due to aging alone or age-related hearing loss. They discovered the reduction of OAE amplitude was due primarily to age-related hearing loss and only a small number of patients with normal thresholds had reduced amplitude (Hoth et al., 2009). It is important to understand age-related hearing loss while working with older canines.

Extrinsic Factors

The first extrinsic factor, probe fit, is critical for obtaining reliable otoacoustic emissions. Probe fit aids in reducing the external noise since a poorly fit probe tip allows environmental noise to interfere with testing and low frequencies to escape the ear (Robinette & Glattke, 2007).

Maxon et al. (1997) analyzed referral rates while screening newborns using transient-evoked otoacoustic emissions. The authors stated that with proper fit, noise levels up to 65 dB SPL could be present while still obtaining a pass while a poor fit allowed noise of 45 dB SPL to enter and caused the patient to be referred (Maxon et al., 1997). Improper fit could be due to the probe tip being too big or too small, the probe not being deep enough, or the probe being pushed against the wall of the external auditory meatus.

Improper probe fit could influence obtaining reliable results in canines. Although there are many similarities between the canine auditory system and the human auditory system, one key difference between the two is the shape of the ear canal. When using probe tips made for human ears, the shape and size of the ear canal might affect the proper fit of the probe tip, e.g., the probe tip not being deep enough, the probe tip hitting the wall of the ear canal, and the probe tip being occluded with wax or foreign bodies that could not be fully visualized during otoscopy.

Another extrinsic factor, the environment in which the otoacoustic emissions are performed, is vital to obtain accurate results since the noise levels must be low. Robinette and Glattke (2007) stated that a sound-treated booth was an ideal test room and noises such as voices, fans, and footsteps must be kept to a minimum. Headley et al. (2000) examined transient-evoked OAEs in five environments in a newborn nursery. The participants in this study were babies who passed a screening auditory brainstem response. The researchers discovered the environments with the least amount of high noise samples were obtained when the participants were tested in a nonfunctioning, quiet isolette (a clear plastic enclosed crib) in the nursery and when the participants were tested in a nonfunctioning isolette in a quiet room away from the newborn nursery. The noise from the isolette and the noise from the newborn nursery caused high noise samples, which resulted in absent otoacoustic emissions from some participants because the noise floor was too high. The testing environment in which otoacoustic emissions are obtained is important to ensure reliable results for humans and canines. Otoacoustic emissions in canines could be obtained at veterinary office, which might have varying noise levels and might cause unreliable results due to the noise floor. Specific ambient noise values at veterinary office are discussed next.

Ambient Noise and Testing

American National Standards Institute, Inc. (ANSI; as cited in Frank, 2000) created guidelines for the maximum permissible ambient noise allowed in audiometric test booths (ANSI S3.1-1999). Tests such as pure tone testing and otoacoustic emissions are typically done in test booths to ensure environmental noise is kept to a minimum; therefore, sound booths must follow these guidelines. By using a sound level meter with an octave band analyzer, these measurements could be obtained at each frequency. The following data from Frank (2000) express the allowable dB SPL levels with A-weighting at specific frequencies: 49 dB at 125 Hz, 35 dB at 250 Hz, 21 dB at 500 Hz, 26 dB at 1000 Hz, 34 dB at 2000 Hz, 37 dB at 4000 Hz, and 37 dB at 8000 Hz.

Ambient noise does not affect BAER testing and therefore was not a factor that needed to be considered. Although the ideal environment for otoacoustic emissions testing is in a sound booth, many environments for screenings have high ambient noise that can be controlled. For canines, otoacoustic emissions might be used as a screening and diagnostic tool for hearing loss in a veterinary clinic. Veterinary offices are potentially prone to high noise levels, which could be produced from machinery, animals, or technicians. The noise levels could be dependent on how busy the clinic is and the type of clinic (e.g., shelter, hospital). The ambient noise might affect which frequencies are testing with otoacoustic emissions. Dhar and Hall (2012) stated that otoacoustic emission frequencies above 1500 Hz were less affected by ambient and physiologic noise.

The National Institute for Occupational Safety and Health conducted a study with Achutan and Tubbs (2007) at an animal hospital where workers wore noise dosimeters over a two-day period. The institute found 10 of the 18 measurements exceeded the National Institute for Occupational Safety and Health standards for safe workplace noise and, specifically, the noise levels ranged from 91 to 95 dBA. Researchers of another study focused on the noise measurements of dogs barking and found the sound pressure levels reached up to 108 dBA in veterinary offices (Senn & Lewin, 1975). Compared to the ANSI standards, these levels clearly exceeded the allowable sound pressure level in a sound booth.

Lee and Kim (1999) conducted a study that measured distortion product otoacoustic emissions in nine different conditions with ambient noise. The participants of this study were 20 normal hearing adults, confirmed with pure tone audiometry, with normal middle ear function. The researchers analyzed the maximum permissible ambient noise level by using pink noise ranging from 30 to 65 dBA. They found that if ambient noise was present, longer averaging times were needed to detect otoacoustic emissions. Lee and Kim noted that ambient noise of 40 dBA or greater affected the noise floor of the otoacoustic emissions in the low frequencies and a level of 55-65 dBA did not affect noise floor of the otoacoustic emissions in the higher frequencies. The specific values of maximum permissible ambient noise levels were dependent on the averaging time. For 0.7 kHz, otoacoustic emissions could not be measured in noise with 1.3 second averaging time and the maximum permissible ambient noise level for averaging times of 2.6 seconds and 5.3 seconds ranged from 25-35 dBA. It was concluded that if distortion product otoacoustic emissions were recorded in a noisy environment, longer averaging times should be used to obtain reliable results for lower frequencies.

Summary of Chapter III

Although many researchers found otoacoustic emissions were a reliable way to assess hearing status in canines, limitations were present. Since there were inconsistencies between studies, more research is needed within the area to discover what parameters and criteria are most suitable for canines.

Many factors could affect the results of otoacoustic emissions including intrinsic and extrinsic factors. Ambient noise and probe fit are important factors that could be controlled when testing canines. Possible solutions and protocols are discussed in the next chapter.

CHAPTER IV

APPROACHES TO THE ISSUE OR CLINICAL PROBLEM: GAPS IN LITERATURE AND FACTORS AFFECTING OTOACOUSTIC EMISSIONS IN CANINES

Proposed Solutions

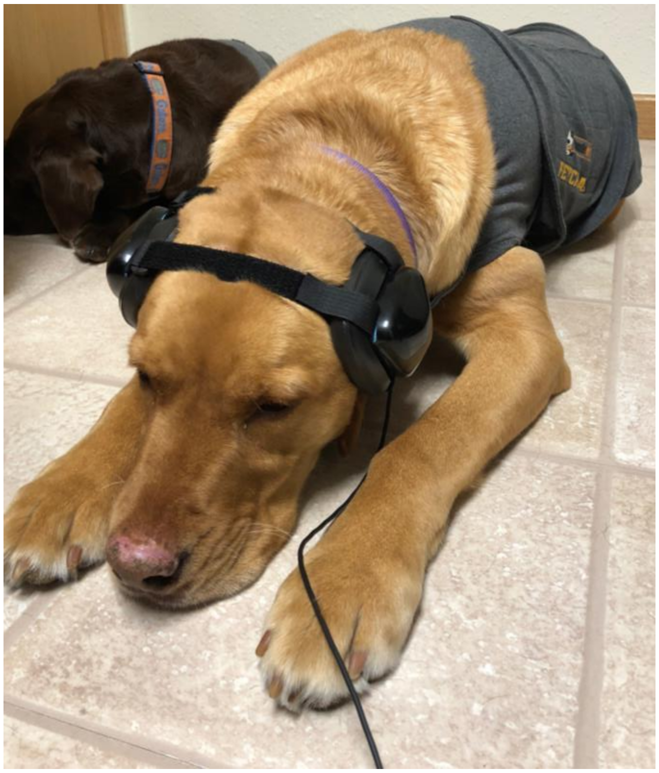
Since otoacoustic emissions require minimal artifact from background noise and movement, it would be essential to find a quiet setting for the testing to be completed. The room should also be free of distraction to try to relax the canine as much as possible. Ideally, the canine would be calm and quiet with minimal movements. Noise levels in veterinarian offices were previously discussed, which indicated that finding a quiet, peaceful room in a veterinarian office might be difficult. Peter Scheifele et al. (2012) analyzed the effect of kennel noise in canines. In their study, the researchers discussed solutions to limit kennel noise, which included proper ventilation and reducing reverberation by limiting bare surfaces. Proper ventilation might reduce ambient noise as well as aid in controlling temperature of the room to avoid excessive panting from the canine. Noisy testing environments might also require more sweeps, thus increasing testing time, which might be difficult for canines who are anxious or active. Finding an ideal setting for otoacoustic emissions is important and should be carefully considered if professionals decide to utilize otoacoustic emission testing as a tool for assessing canine hearing status. This might include utilizing a space that is far away from kennels and people or screening otoacoustic emission during a time of day when the clinic is not very active.

Professionals within the field of audiology or within the field of veterinary medicine should be trained on how to properly test and interpret otoacoustic emissions. Trained professionals should also understand when it is appropriate to make referrals for BAER testing and how to properly counsel owners if their dog does have hearing loss. This multidisciplinary approach is explained later in the document.

It might be difficult for a canine to cooperate and keep the probe tip in its ear. Since probe fit is vital to obtaining reliable otoacoustic emissions, a device could be used to secure the probe tip in the ear. Mutt Muffs (Safe and Sound Pets, 2021) are earmuffs typically used as hearing protection for dogs but could be used to hold the otoacoustic emission probe in place. A canine wearing Mutt Muffs is shown in Figure 8. Gonçalves et al. (2012) stated they used an ear cover to attenuate noise and although the specific brand was not named, the device was similar to Mutt Muffs. The muffs consisted of a band that was strapped around the dog's head. The inner foam was similar to the material used in human hearing protection. The estimated decibel reduction was between 25 and 28 dB with proper fit and a good seal. Not only did the muffs keep the probe tip and place and allow for consistency of probe tip placement but they might also have had a relaxing effect as the canines did not try to shake the probe out of their ear as they would without the muffs.

Figure 8

Canine Wearing Mutt Muffs Over the Top of the Probe Tip in the Left Ear



Innovative Technology

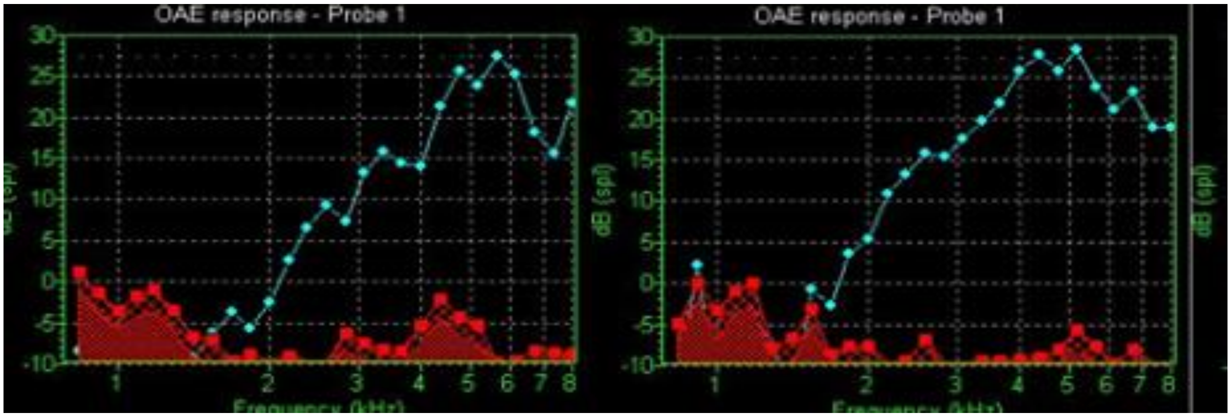
Although it was not their primary purpose, Mutt Muffs (Safe and Sound Pets, 2021) have been utilized to aid in proper probe fit. Banded earmuffs could be created solely to be used to hold the probe tip in place and to aid in the attenuation of outside noise. The design could be verified by research to ensure the probe tip is being properly held in the ear without causing artifact.

Similarly, a new probe tip could be invented that is designed for the canine ear. This probe tip could come in various sizes, taking into account the “L” shape of the canine ear canal. The probe could be surrounded with soft foam for comfort with the tip being inserted deep into the canal. The soft foam would expand in the canal, ensuring that sounds did not leak in or out of the ear canal. Dhar and Hall (2012) stated that ambient noise would be reduced by deeper insertion and tighter coupling of the probe tip. The best placement for the probe in canines would be at Noxon's Ridge to ensure the probe tip does not hit the walls of the ear canal since the canal takes a 90-degree turn at this anatomical site. These inventions could ensure proper probe fit and consistent placement of the probe tip over multiple test sessions.

The parameters selected for human otoacoustic emissions have been verified by extensive research. Currently, no specific parameters have been researched for the use of otoacoustic emissions in canines. The most commonly used f2/f1 ratio for eliciting DPOAEs in healthy adults is between 1.20 and 1.22 (Petersen et al., 2017) and is currently unknown in canines. One research project by Hartson (2021) investigated what f2/f1 DPOAE ratio yielded the best results for canines by modifying f1 to make the ratios 1.18, 1.20, 1.21, 1.22, 1.23, 1.24, 1.25, 1.26, and 1.28. This researcher found ratio 1.18 and 1.20 at 2000 Hz and above yielded the best results in canines. Examples of DPOAE results from that study, which utilized Mutt Muffs (Safe and Sound Pets, 2021) to secure the probe tip, are displayed in Figure 9. This figure demonstrates that OAEs were best displayed above 2000 Hz in canines. Future research should continue to investigate OAE parameters in canines.

Figure 9

Otoacoustic Emission Responses from a Canine Wearing Mutt Muffs



Note. Permission obtained from Hartson (2021).

Multidisciplinary Perspective: Setting Up an Otoacoustic Emission Test Site

A multidisciplinary approach should be used for otoacoustic emission testing in canines. It is important that animal audiologists, veterinarians, veterinary technicians, and owners are part of the multidisciplinary team. Animal audiologists are equipped with the proper coursework in animal behavior, anatomy of animal auditory systems, restraint techniques, objective evaluation of the canine auditory system, and hearing loss in canines. This coursework, along with clinical experience administering BAER on animals, allows them to properly administer and interpret tests on canines.

The first step in setting up an otoacoustic emission test site for canines is ensuring the multidisciplinary team can work together. An agreement should be made between the veterinary office and animal audiologist. Once this agreement has been made, it is important for the animal audiologist to train staff on the importance of diagnosing hearing loss in canines and how otoacoustic emission could diagnose hearing loss in canines. Animal audiologists would also provide training on proper fit of the otoacoustic emission probe, factors that could affect testing and how to properly interpret results.

Veterinary offices should take into consideration the testing environment using data from Peter Scheifele et al. (2012) to ensure the canines are comfortable and ambient noise is low. This room should be measured with a sound level meter. Using data from Lee and Kim (1999) and ANSI (as cited in Frank, 2000) standards, the level should not exceed 55-60 dBA. To reduce ambient noise, the walls should be covered with soft material. Ideally, the room would be as far away from loud machinery and dog kennels and would be well ventilated.

An OAE system equipped with diagnostic testing should be used so animal audiologists could further interpret the results. Many otoacoustic emission systems have the option to choose screening mode or diagnostic mode and diagnostic mode should always be used in this setting to allow for thorough interpretation of the results. Once the diagnostic system was attained, normative data were obtained on canines with normal hearing. Hall (2015a) stated the first step in interpreting otoacoustic emissions in humans was to compare the response to the normative data for the system. Although normative data for canines did not currently exist, Hall stated it could be simple to collect normative data with otoacoustic emissions. According to Hall, it was recommended to collect otoacoustic emissions on at least 10 people with normal hearing sensitivity and enter that data into the system being used to collect a reference graph of normative data. For canines, the similar process could be conducted by using otoacoustic emissions data from canines who had normal hearing as verified by BAER testing. This normative data could be displayed on the OAE graph. Since there is not a lot of research in this area, the normative data collected could be useful in the interpretation of results.

It is important that the team work together and be trained appropriately. It is also important to have access to the proper resources including the otoacoustic emission diagnostic equipment and a quiet, safe environment for testing. The steps in setting up this program are summarized in Figure 10. If no animal audiologists are in the area, then the veterinary professional could be trained on administration of OAEs and the results could be sent to an animal audiologist to be interpreted.

Figure 10

Summary of Steps Involved in Setting Up an Otoacoustic Emission Test Site

First steps in starting an OAE test site

- Step 1: Find a veterinary office who is willing to work with animal audiologists
- Step 2: Train veterinary personnel on OAE administration and interpretation
- Step 3: Ensure the proper environment for testing
- Step 4: Obtain OAE diagnostic equipment
- Step 5: Obtain normative data with equipment

Multidisciplinary Perspective: Administering the Testing at the Otoacoustic Emission Test Site

Veterinarians and veterinary technicians should provide the first step in this process by checking the overall health and wellbeing of the canine. They are also an important asset to the team to prescribe medication for otitis media and otitis externa if necessary. Animal audiologists on the multidisciplinary team would provide diagnostic testing and interpretation of results.

These trained professionals could interpret results and decide if auditory brainstem responses should be used in conjunction with otoacoustic emission testing. Animal audiologists and trained veterinary personnel would administer otoacoustic emission—step two in the process of evaluating the hearing status of canines. As stated above, it is important to train veterinary personnel on proper probe fit and factors that could affect test results.

Distortion product otoacoustic emissions should be the preferred test for canines since DPOAEs are able to test higher frequency responses; however, DPOAEs take longer to record. Transient evoked otoacoustic emissions could be used in conjunction with DPOAEs to verify the status of the inner ear. Transient evoked otoacoustic emissions could also be used as a quicker method to obtain results in canines that might have trouble sitting still and quiet for a long period of time. Transient evoked otoacoustic emissions are also able to be analyzed with a higher noise floor compared to DPOAEs; therefore, if the noise floor cannot be reduced with DPOAEs, then TEOAEs should be used. Pending the completion of further research, the following parameters in Table 2 should be used, which are based on previous research of otoacoustic emissions in canines and in humans including the research by Hartson (2021). After otoacoustic emissions are obtained and follow the criteria listed below, the results should be saved and the otoacoustic emissions should be run again to ensure repeatability.

Table 2

Suggested Parameters for Otoacoustic Emission in Canines

Parameter	Suggested Parameter for OAE Testing in Canines
Stimulus level	DPOAE: ratio of 1.18 or 1.20 65/55 dB SPL TEOAE: 85-90 dB SPL
Frequency Range	DPOAE: 2,000 Hz to 10,000 Hz TEOAE: 2,000 Hz to 4,000 Hz
SNR Criteria	6 dB SNR
Reproducibility	75% or higher
Stimulus Stability	Around 100%, if less then 70% discard and retest

For interpretation of results, the otoacoustic emission should be 6 dB above the noise floor and the animal audiologist should examine the results by analyzing the amplitude of the response at each frequency. The otoacoustic emission at each frequency response should be labeled as normal, abnormal but present, or absent. It is up to the animal audiologist's expertise and discretion to assume normal inner ear function depending on how many frequency bands or points of the otoacoustic emissions were labeled normal. For example, if majority of the responses (e.g., four out of six) were labeled as normal, then the animal audiologists could assume proper function of the inner ear. Conversely, if four out of six responses were considered absent, then the animal audiologist could assume abnormal middle or inner ear function. The team should further investigate and follow the protocol for next steps. As previously mentioned, normative data could be collected and used to compare the results to the responses of canines with normal hearing confirmed by BAER testing.

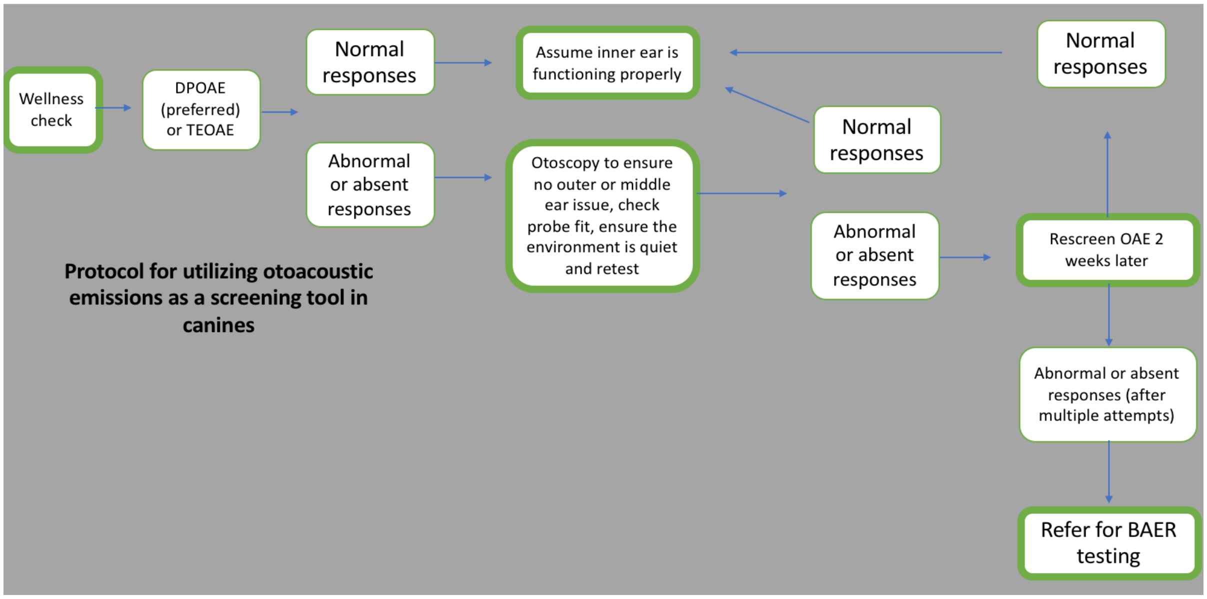
Owners should also be part of the multidisciplinary team as they need be informed of the status of their dog's hearing for training and/or breeding purposes. Animal audiologists could also provide resources and education to owners who had dogs with hearing loss and bring awareness to hearing loss in canines. According to Lisa Scheifele et al. (2012), once hearing loss is verified and the appropriate medical treatment is pursued, if applicable, then owners should be educated on ways to adapt the human/canine relationship. The researchers stated that eye contact and hand signals should be the primary mode of communication. Owners should also be aware of safety hazards including canine unresponsiveness to environmental alerting sounds such as alarms or horns as well as unresponsiveness to verbal commands and verbal expressions.

Screening and Diagnostic Use of Otoacoustic Emissions

Otoacoustic emission test sites could provide both screening and diagnostic testing. For screenings, professionals should refer to the flow chart in Figure 11 for canines who have abnormal otoacoustic emissions. The chart provides a guideline for when professionals should refer a canine for BAER testing to confirm hearing status. Examples of when to refer a canine for screening would be for breeders who would like to check the hearing status of their puppies, service dogs, and dogs in a shelter waiting to be adopted. A diagnostic referral should be made when the owner has concerns with hearing and there are signs the dog might have hearing loss. Signs of hearing loss in canines (Lisa Scheifele et al., 2012) include, but are not limited to, trouble localizing sounds, unaware of environmental sounds, unaware of verbal commands, difficulty waking the dogs, and confusion or agitation in familiar settings. For diagnostic testing, otoacoustic emissions would be performed before or after BAER testing and results from both tests would then be reviewed by the multidisciplinary team. The team would then provide owners with the proper referral, recommendations, and resources.

Figure 11

Flow Chart for the Otoacoustic Emissions Screening Process in Canines



As previously mentioned, the first step includes veterinary professional completing a wellness check and then otoacoustic emissions are administered. If the canine does not pass the first time, it is important to perform otoscopy to check for outer or middle ear pathologies. As previously mentioned in Chapter III, outer and middle ear pathologies could affect the results of otoacoustic emissions. These pathologies include impacted cerumen, foreign bodies, and otitis media, and should be ruled out as the cause of hearing loss while interpreting otoacoustic emissions. If the canine does not pass again, they should be rechecked in two weeks in case there is a middle ear pathology that needs time to resolve.

Cost analysis of testing was taken into consideration while preparing this protocol. The following amounts are given as an example. For diagnostic testing where OAE and BAER testing are performed together, the cost is $85. For OAE screening, the cost is $40 and if follow-up visits are required, that visit costs $45, which would include another OAE test and BAER test if necessary.

CHAPTER V

SUMMARY AND FUTURE DIRECTIONS

Otoacoustic emissions have been a useful and reliable screening and diagnostic tool in humans and likely could be similarly used in canines by assessing the status of the outer hair cells within the canine cochlea. Like humans, canines are also susceptible to congenital and acquired hearing loss. As Lisa Scheifele et al. (2012) concluded, diagnosing hearing loss in canines could provide owners with distinctive training methods and a safer environment.

Current research showed that otoacoustic emissions could be a useful tool to measure hearing loss in canines; however, some limitations were present. Future studies should investigate the best parameters and protocol for canines and evaluate the ideal setting to measure otoacoustic emissions. Until then, suggested parameters were available in Table 2. It is vital that the multidisciplinary team work together to provide the best testing environment and professional recommendations.

Before professionals within the field of animal audiology and veterinary medicine can implement otoacoustic emissions as a tool to assess canine hearing status, many factors must be taken into consideration. Ambient noise and physiological noise could impact the results of testing so the testing environment must be quiet and the canine must be cooperative. The fit of the probe tip is key in obtaining accurate otoacoustic emissions; therefore, professionals must be trained on how to adequately place the tip in the canine ear canal. Future research could invent a probe tip suitable for the canine ear and equipment such as Mutt Muffs (Safe and Sound Pets, 2021) could be used to secure the probe tip and to eliminate outside noise. Once testing is completed, it is important that professionals accurately interpret the results using the suggested parameters in Table 2.

McBrearty and Penderis (2011) stated that the use of otoacoustic emission testing as a screening tool could be used similar to that of infants. Puppies that failed could be retested at a later date and then referred for BAER screening to confirm hearing status. Professional should use the flow chart from Figure 11 in this process. Otoacoustic emissions could also be used in conjunction with BAER testing to provide a full diagnostic battery and to provide frequency specific information. This document provided guidelines and parameters based on previous research in humans and canines for utilizing otoacoustic emissions in canines.

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